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RESEARCH MEMORANDUM

EFFECTS OF SEVERAL ARRANGEMENTS OF RECTANGULAR
VORTEX GENERATORS ON THE STATIC-PRESSURE
RISE THROUGH A SHORT 2:1 DIFFUSER

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RESEARCH MEMORANDUM

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SUMMARY

An investigation was made of a 2:1 area-ratio diffuser of length equal to the inlet diameter with several arrangements of simple rectangular vortex generators over a speed range up to an inlet Mach number of 0.5. The investigation was for an inlet boundary layer of 5 percent of the inlet diameter, a condition for which this diffuser had substantial separated areas with no vortex generators. The effects varied considerably between different vortex-generator arrangements. Some arrangements actually reduced the diffuser static-pressure rise. The effect of one of the better vortex-generator arrangements was to increase the diffuser effectiveness by 30 percent; this arrangement made it equal to that of a diffuser of twice the length with no vortex generators.

INTRODUCTION

The ineffectiveness of wide-angle conical diffusers has been shown by previous investigations to be associated with separation of the flow from the diffuser boundary. The separation results from the inability of the flow to negotiate the high static-pressure gradient required by the rate of expansion of the diffuser area. A substantial part of the cross section at and beyond the first separation is then occupied by low or negative velocity air. The main mass flow of air is then taking place through a reduced area and, consequently, at considerably higher speed. Effectively, the area ratio has been reduced below the geometric value. The skin-friction losses over the unseparated surfaces will be greater and the over-all static-pressure rise less than if no separation had taken place. Some further insight into the mechanism of the diffusion process and its relation to the characteristics of the boundary layer may be gained by a study of references 1 and 2. Reference 2 brings

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out that the flow in a conventional, smooth, short diffuser is definitely a three-dimensional phenomena lacking axial symmetry and that it is dependent on the initial boundary layer and Mach number as well as on the area-ratio change accomplished in a given length.

The obvious method of avoiding boundary-layer separation in a diffuser would, of course, be to increase its length and thereby decrease the adverse pressure gradient. Since, in many practical cases, space limitations do not permit this solution, any other method of preventing or delaying separation effects in a diffuser is of interest and should be evaluated.

The goal of many investigators has been to increase the ability of the turbulent boundary layer to transmit momentum. One of the suggested ways of accomplishing the increase has been the use of the mixing resulting from the tip vortices of short wings mounted normal to the diffuser surface, herein called the vortex generators.

Application of vortex generators to reduce the power requirement of a large wind tunnel was investigated by the United Aircraft Corporation (reference 3). The effect on separation from a flat plate with an adverse pressure gradient was observed for a large number of vortex-generator arrangements. The results were used to indicate suitable vortex-generator arrangements for experimental investigation in alternate 10° , 20° , and 30° , 4:1 area-ratio diffusers installed in a model of the large tunnel. The results of this investigation show the vortex generators to have beneficial effects on separation and on pulsing- or unsteady-flow conditions generally attributed to separated flows.

In reference 2, a short 2:1 area-ratio diffuser with a 23° cone angle was shown to have extensive separation areas for the thicker inlet boundary-layer condition. This condition was for an inlet boundary-layer thickness of the order of 5 percent of the inlet diameter. The static pressure was substantially less than the theoretical value and there was considerable flow fluctuation.

The present investigation was undertaken to determine whether simple vortex-generator arrangements installed near the inlet could be used to improve the operating characteristics of this short diffuser when operating with the thicker boundary layer. The investigation was limited in that only one size and shape of vortex generator was to be used. The main physical variables were to be the angle of attack and the number and location of the vortex generators.

Although the primary purpose in installing the vortex generators was to delay or prevent separation and thereby increase the amount of

static-pressure recovery that could be accomplished in a given length, it was also considered that the further advantage of steadier flow conditions might be realized.

SYMBOLS

p	static pressure
H	total pressure
ρ	mass density
R	gas constant
γ	ratio of specific heats
q_{c1}	impact pressure $(H_1 - p_1)$
Δp	wall static-pressure rise
$\Delta p / \Delta p_{ideal}$	diffuser effectiveness
d	tube diameter
b	spanwise dimension of vortex generator
c	chord of vortex generator
s	middle arc length between vortex generators
n	number of vortex generators

A bar over a symbol indicates an average value.

Subscripts:

0	reference conditions
1	diffuser inlet conditions
6	diffuser exit conditions
7	tail-pipe exit conditions

APPARATUS AND METHODS

General arrangement.- The apparatus for this investigation is that used for part of the investigation of reference 2 and is shown diagrammatically in figure 1. This apparatus consists of a 23° conical diffuser joined to a 21-inch-diameter cylindrical entrance section by a transition shape which, in axial section, is an arc of $5\frac{3}{16}$ -inch radius tangent to both the cylindrical and the conical parts. The cylindrical entrance section was about $4\frac{1}{2}$ inlet diameters in length and was preceded by an entrance bell which provided the reduction from the 54-inch ducting leading from the blower. As in reference 2, a tail pipe $3\frac{1}{2}$ inlet diameters in length was in place. A photograph of the duct arrangement is shown in figure 2. The boundary-layer survey instrument and the exit-pressure-loss rakes indicated in the photograph were not in place for this investigation. All internal surfaces were kept in good smooth condition during the course of the investigation.

Basis of selection of preliminary vortex-generator arrangements.- Reference 3 gives some general recommendations for effective vortex-generator arrangements. These are based on observation of tufts on a flat plate on which vortex generators were installed for tests under various conditions of adverse pressure gradient. Rectangular airfoils were described as probably being nearly as effective as the tapered plan form indicated by their theory. A ratio of span to chord of 1 to 2 was regarded as suitable with a spacing of about three times the span. "Counterrotation" was recommended, each airfoil having an angle of attack of opposite sign to that of the ones next to it. The recommended location, however, was relative to the "plane of separation" and was not directly usable because, as already described, the "plane of separation" is a meaningless term for this diffuser. If the recommendation of reference 3 were interpreted as being relative to the first separated region shown by the tufts, the location would be well into the entrance pipe. This, if applicable in general, would limit interest in the use of the vortex generators for a diffuser similar to this one since, if this length were available, it would generally be used to make the diffuser longer. The recommended span length was of the order of the boundary-layer thickness. Since the inlet boundary layer was about 1 inch, NACA 0012 airfoils of 2-inch chord were cut to 1-inch span lengths to conform to the span length and the span-to-chord recommendations. The spacing and other recommendations resulted in the initial use of 22 of these vortex generators counterrotating. Figure 3 shows a set of the vortex generators placed 1 inch downstream of station 1. This location is farther downstream than appeared to be indicated by the information

of reference 3 but location farther upstream would increase the length allowed for the diffuser action to take place. This location will be referred to as the inlet vortex-generator location as all vortex generators were installed at this location with the exception of a short series of runs in which the effect of the longitudinal location was investigated. This location and arrangement were considered as a good starting point in general practical agreement with the recommendations from reference 3. Experimental investigation was intended to show whether this or some other arrangement was a good selection for this 2:1 area-ratio short diffuser with a thick initial boundary layer.

Instrumentation.- Static-pressure measurements were made at six radially distributed positions at stations 1, 6, and 7 of figure 1. A single line of flush static orifices extended upstream of the diffuser inlet. Static-pressure measurements at these points and the readings from the total-pressure tube in the large duct upstream of the setup constitute the quantitative data of this investigation. Wool tufts were installed in the diffuser to give indication of separation regions and flow stability and uniformity.

Basis of comparison of vortex-generator arrangements.- In this work a number of vortex-generator arrangements were to be investigated and a quick method of evaluating the relative performance of each was required. An arithmetic average of the pressures from the circumferentially distributed static-pressure orifices at station 6 was used for the diffuser exit pressure. For an inlet static pressure, use was made of one of the taps in the inlet pipe sufficiently upstream to be out of the local pressure field of the vortex generators and also not affected by separation areas in the diffuser. These two static-pressure values were used with the upstream total-pressure reading to compute values of $\Delta p/q_{c1}$. This procedure was adopted after consideration of the early data. The pressure from one of the pressure orifices at station 7 was used for the pressure at the end of the tail pipe.

Computation and presentation of data.- For the preliminary work of evaluation of the different vortex-generator arrangements, the results are presented as $\Delta p/q_{c1}$. The value of p_1/H_0 was used as an inlet flow rate and Mach number parameter. For the most effective arrangement, the results are presented in terms of diffuser effectiveness $\Delta p/\Delta p_{ideal}$ to permit a direct comparison with the results of reference 2.

RESULTS AND DISCUSSION

Diffuser with no vortex generators.- One of the purposes of the present investigation was to give detailed attention to the flow in the

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diffuser. Tuft observations with the bare diffuser showed areas which were clearly unseparated and other areas definitely separated. These areas, however, shifted position around the diffuser from time to time. In general, a specific point on the diffuser surface would be at times separated and at other times unseparated. Observation of the manometer indicated that, during this process, the tubes of station 1 as well as those of station 6 fluctuated between two fairly definite patterns which are referred to as state a and state b. The separation regions in this diffuser influenced the surface static pressures clear up into the inlet and beyond any separated region indicated by the tufts. The single static pressures upstream of station 1 were not affected in this way. Figure 4 shows the variation in circumferential static pressure relative to the average static pressure at station 1 for the diffuser inlet and outlet and for the tail-pipe outlet. There are two curves for both the diffuser inlet and the diffuser outlet corresponding to the two conditions, state a and state b, in which the flow stabilized for most of the time. At the diffuser inlet station, which is still in the cylindrical part, the circumferential static-pressure variation is 15 percent of the inlet dynamic pressure at both flow rates. This result is at variance with the assumption, usually thought justified, that the static pressure for any station along a straight constant-area tube may be considered uniform over the entire cross section. At the diffuser exit the variation is still as much as 7 percent of the inlet dynamic pressure for both flow rates. At the tail-pipe exit, however, the variation has become negligible in each case.

In figure 5 is shown the apparent two-valued pressure-rise characteristics that would be obtained if single tube readings were depended upon to give the static pressure representative of stations 1 and 6. These points are from the readings for the tubes plotted at 0° in figure 4 and would lead to the conclusion that the diffuser has two operating conditions differing considerably in their resulting static-pressure rises. In contrast to this, the points in figure 6, which were obtained by using an arithmetic average of the values for station 1 and also an average for station 6, give results which do not differ much for the two apparent operating conditions. Averages were therefore used throughout the program for the diffuser outlet as already stated under the section entitled "Apparatus and Methods." Since the static orifices at the diffuser inlet would be in the local pressure field of the vortex generators, a single orifice upstream from this influence was used to obtain the inlet static pressure. The use of an upstream orifice gives a conservative result since some of the pressure drop along the pipe is being subtracted from the pressure rise attributed to the diffusion process.

Figure 6 indicates that considerable pressure recovery takes place in the tail pipe. A similar pressure recovery in the tail pipe was also

obtained in the results from the same diffuser in reference 2. In fact figure 6 represents a duplicate condition to the thicker boundary-layer investigation of reference 2. However, the results are presented on a different basis and slightly different measuring-tube positions were used. When changed to the same basis and corrected for the measurement-technique differences, the results from reference 2 are then in what is considered good agreement with the present results considering the possibility of differences due to elapsed time, reassembly of the duct system, and the different method of dealing with the fluctuation of the flow conditions.

All diffuser static-pressure recoveries of this investigation were from measurements of static pressure at the diffuser inlet and outlet and were made with the tail pipe in place. This condition was also true for the investigation of reference 2. However, no data indicate that the vortex-generator effects measured with a tail pipe in place are not equally applicable to vortex-generator installations in diffusers intended to operate with no tail pipe in place.

Counterrotating vortex generators.- The static-pressure rise in the diffuser for 22 counterrotating vortex generators at three different angles of attack is shown in figure 7 in terms of the indicated inlet dynamic pressure. This rise is the pressure recovery up to the end of the diffuser and includes no gains obtained in the tail pipe. The curve from figure 6 for the diffuser without vortex generators is included for ready comparison. As in the case of the bare diffuser, two fairly definite operating conditions were found at which the flow would stabilize for each of the three angles of attack. The vortex generators improved the pressure recovery over this speed range for all three angles of attack with the 15° setting having the best over-all effect.

The circumferential static-pressure distribution at the diffuser exit is given for two flow rates in figure 8 for 22 counterrotating vortex generators set at 15° and for 22 vortex generators set at 20° . For the angle of attack giving the greatest pressure rise, 15° , the exit static-pressure variation at the lower flow rate is quite small and is considerably less than for the corresponding curve of figure 4 for the bare diffuser. For the less effective 20° setting, the variation at the lower flow rate was greater. For both the 15° and the 20° setting, there was considerable nonuniformity at the higher flow rate.

Cross plots of the pressure rise in the diffuser for angles of attack of 0° , 15° , 17.5° , and 20° are given in figure 9 for two flow rates. The 0° values are from a straight-line interpolation between 0° values measured with 14 vortex generators and with 28 vortex generators. An angle of attack of around 17° appears from this result to be favorable for 22 counterrotating vortex generators at the lower flow rate and an angle of attack of about 15° for the higher flow rate.

The pressure rise in the diffuser with the 22 counterrotating vortex generators never reached the value of over 0.6 obtained at the end of the tail pipe with no vortex generators. (See fig. 7.) The values obtained at the end of the tail pipe with 22 counterrotating vortex generators set at 15° are shown in figure 10. The curve for no vortex generators is repeated from figure 6. In this case, the pressure recovery at the end of the tail pipe with the vortex generators exceeds that with no vortex generators except at the highest speed.

The effect of varying the number of these vortex generators was investigated by also running tests with 14 and with 28 counterrotating vortex generators. With 14 vortex generators the results were not particularly favorable. However, with 28 counterrotating vortex generators set at 15° (see fig. 11(a)) the pressure rise through the diffuser was higher over most of the speed range than that for the diffuser with tail pipe when no vortex generators were used. In addition, there was still some pressure rise in the tail pipe. Figure 11(b) for 28 vortex generators set at 20° shows pressure recoveries smaller than those for the 15° setting. Reference to figure 12 shows that the circumferential static-pressure distributions at the end of the diffuser for 28 counterrotating vortex generators at 15° was quite uniform as contrasted with the distributions with the diffuser by itself (fig. 4) and with the higher speed run with the diffuser and 22 counterrotating vortex generators (fig. 8).

The effect of number of vortex generators set at 15° is shown in figure 13 which gives cross plots at two flow rates from information obtained with 0, 14, 22, and 28 vortex generators. These data indicate that no advantage is gained by less than 14 vortex generators. Above 14, however, the diffuser pressure recoveries for both flow rates increase with the number of vortex generators up to 28, the largest number investigated.

Other arrangements investigated.— A small part of this investigation was on the effects of longitudinal location of the vortex generators and on the effect of corotation as differentiated from counterrotation of the vortex generators. If the effects are considered to be mainly the mixing action from the tip vortices of the airfoils, the longitudinal location of the airfoils relative to the first separation areas of the bare diffuser could be expected to have a definite relation to the static-pressure rises observed. Whether the corotating or the counterrotating arrangement were used would also be an important factor.

At the low flow rate, moving the vortex generators upstream one-fourth of the inlet diameter improved the pressure recovery slightly at 15° and considerably at 20° . (See fig. 14(a).) Moving the vortex

generator one-half the inlet diameter upstream gave a further increase over the position one-fourth the inlet diameter upstream. Figure 14(b) for the higher speeds shows a similar but even more favorable result. This result confirms the idea that the effect is, at least in part, a mixing effect. Points at 15° with the vortex generators 0.36d downstream of the inlet vortex-generator station are also included in figure 14. These vortex generators were in the conical part of the diffuser and in a region in which the flow for the bare diffuser gave separated areas. The static-pressure recoveries, lower than with no vortex generators, support the conclusions from reference 3 that the vortex generators must be upstream of the original separation area.

The theory and experiment of reference 3 indicated that more favorable results could be expected from counterrotating than from corotating vortex generators. Some check on this result was made for this diffuser by running 22 and 28 corotating vortex generators at angles of attack of 15° and 20° . The more favorable results of the 22 and 28 corotating vortex-generator arrangements are shown in figure 15. Curves for no vortex generators and for 28 counterrotating vortex generators are repeated to facilitate comparison. The two corotating arrangements are better than the arrangement with no vortex generators but not as favorable as the counterrotating vortex-generator arrangement. In fact, neither corotating arrangement (fig. 15) has as great a pressure rise in the diffuser as can be obtained with 22 counterrotating vortex generators (fig. 7).

The circumferential static-pressure distribution at the diffuser exit, figure 16, was, however, quite good for both corotating arrangements. The exit static-pressure distribution for 22 corotating vortex generators set at 20° was very good in contrast to the poor distribution (fig. 8(b)) for 22 counterrotating vortex generators set at 20° .

As a check on whether a simple obstruction would have a favorable effect similar to the effects from the so-called vortex generators, a few additional arrangements were tested. These tests included running the diffuser with 28 vortex generators at 0° angle of attack, 28 rods $1/8$ inch by 1 inch projecting in from the surface, and 28 rods $3/8$ inch by 1 inch projecting in from the surface. In every case, the pressure recovery in the diffuser and in the diffuser plus tail pipe was substantially less than with the unobstructed diffuser.

Comparison with results from previous diffuser research. - If the values of static-pressure rise as a fraction of indicated inlet dynamic pressure given in this report are divided by 0.75, they become values of diffuser effectiveness $\Delta p_{\text{actual}}/\Delta p_{\text{ideal}}$ on the basis of assumption of incompressible-flow relations and uniform-velocity profiles. These same assumptions were used in obtaining the diffuser effectiveness in

references 1 and 2. Values of diffuser effectiveness for the best vortex-generator arrangement investigated, 28 counterrotating vortex generators set 15° , have been plotted in figure 17 for the diffuser and for the diffuser plus tail pipe. Curves for no vortex generators from figure 7 of reference 2 are included. The diffuser effectiveness of the diffuser with this vortex-generator arrangement is about equal to that of the bare diffuser plus tail pipe. There is also some pressure rise in the tail pipe making the effectiveness of the diffuser with vortex generators and tail pipe greater than that of the bare diffuser plus tail pipe. The diffuser effectiveness obtainable with the 28 counterrotating vortex generators at 15° is, for the speed range investigated, practically the same as that of a similar diffuser of twice the length (reference 1).

CONCLUSIONS

The following conclusions relate to the static-pressure rise measured in a 2:1 short conical diffuser of length roughly equal to the inlet diameter and do not consider the total-pressure losses. All comparisons are from measurements made with a tail pipe in place. The inlet boundary layer had a thickness of 5 percent of the inlet diameter. The conclusions are for a single vortex-generator configuration which was rectangular and noncambered and had a spanwise length of one-half the chord.

1. The effect of one of the better vortex-generator arrangements was to make the diffuser effectiveness $\Delta p/\Delta p_{ideal}$ equal to that of a diffuser of twice the length with no vortex generators. This result was obtained by using 28 counterrotating vortex generators set at 15° .

2. The greatest diffuser static-pressure rise with vortex generators was 30 percent greater than that of the diffuser with no vortex generators.

3. For the most effective vortex-generator arrangements the greatest pressure rise was obtained with an angle of attack in the range from 15° to 18° .

4. The pressure rise obtained varied considerably with the arrangement of the vortex generators. One arrangement with the vortex generators in the part of the diffuser for which the flow was separated actually reduced the static-pressure rise below that for the diffuser with no vortex generators. Location of the vortex generators farther upstream of the inlet is favorable but ordinarily would not be done as an alternative to using the space to make the whole diffuser longer.

5. Increasing the number of vortex generators from 22 to 28 increased the static-pressure rise and an even greater number of vortex generators might give an additional increase in the static-pressure rise.

6. Corotating vortex-generator arrangements did not give as high pressure-rise ratios as were obtained with counterrotating arrangements.

7. The flow in the bare diffuser and with many of the vortex-generator arrangements seemed to stabilize intermittently in two different states, depending on chance angular orientation of the separated areas in the diffuser. This flow irregularity was evidenced by a circumferential variation in static pressure at the inlet and at the diffuser exit. Vortex-generator arrangements giving good pressure recoveries also gave uniform static pressures around the circumference of the diffuser exit.

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REFERENCES

1. Copp, Martin R., and Klevatt, Paul L.: Investigation of High-Subsonic Performance Characteristics of a 12° 21-Inch Conical Diffuser, Including the Effects of Change in Inlet-Boundary-Layer Thickness. NACA RM L9H10, 1950.
2. Persh, Jerome: The Effect of the Inlet Mach Number and Inlet-Boundary-Layer Thickness on the Performance of a 23° Conical-Diffuser - Tail-Pipe Combination. NACA RM L9K10, 1950.
3. Taylor, H. D.: Application of Vortex Generator Mixing Principle to Diffusers. Concluding Report. Air Force Contract W33-038 ac-21825. U.A.C. Rep. R-15064-5, United Aircraft Corp. Res. Dept., Dec. 31, 1948.

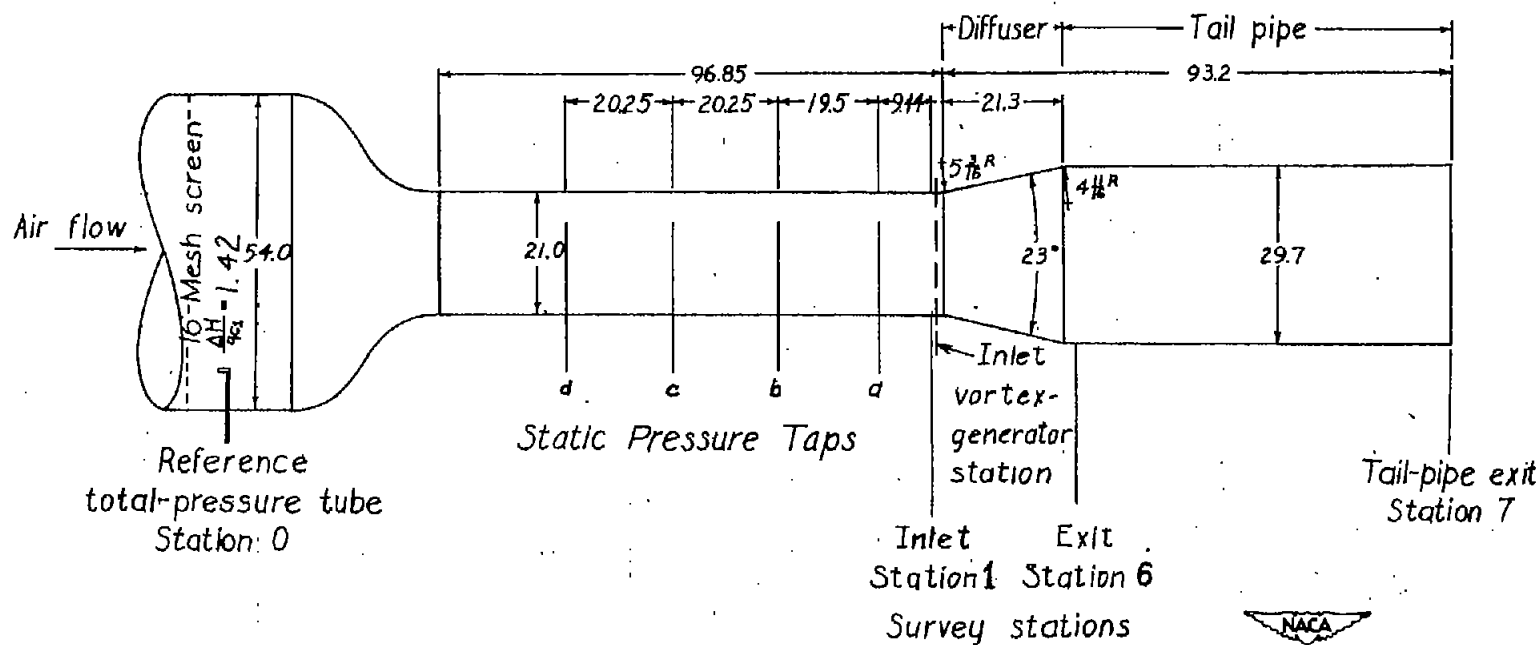


Figure 1.- General arrangement of test apparatus and instrumentation.
All dimensions are in inches.

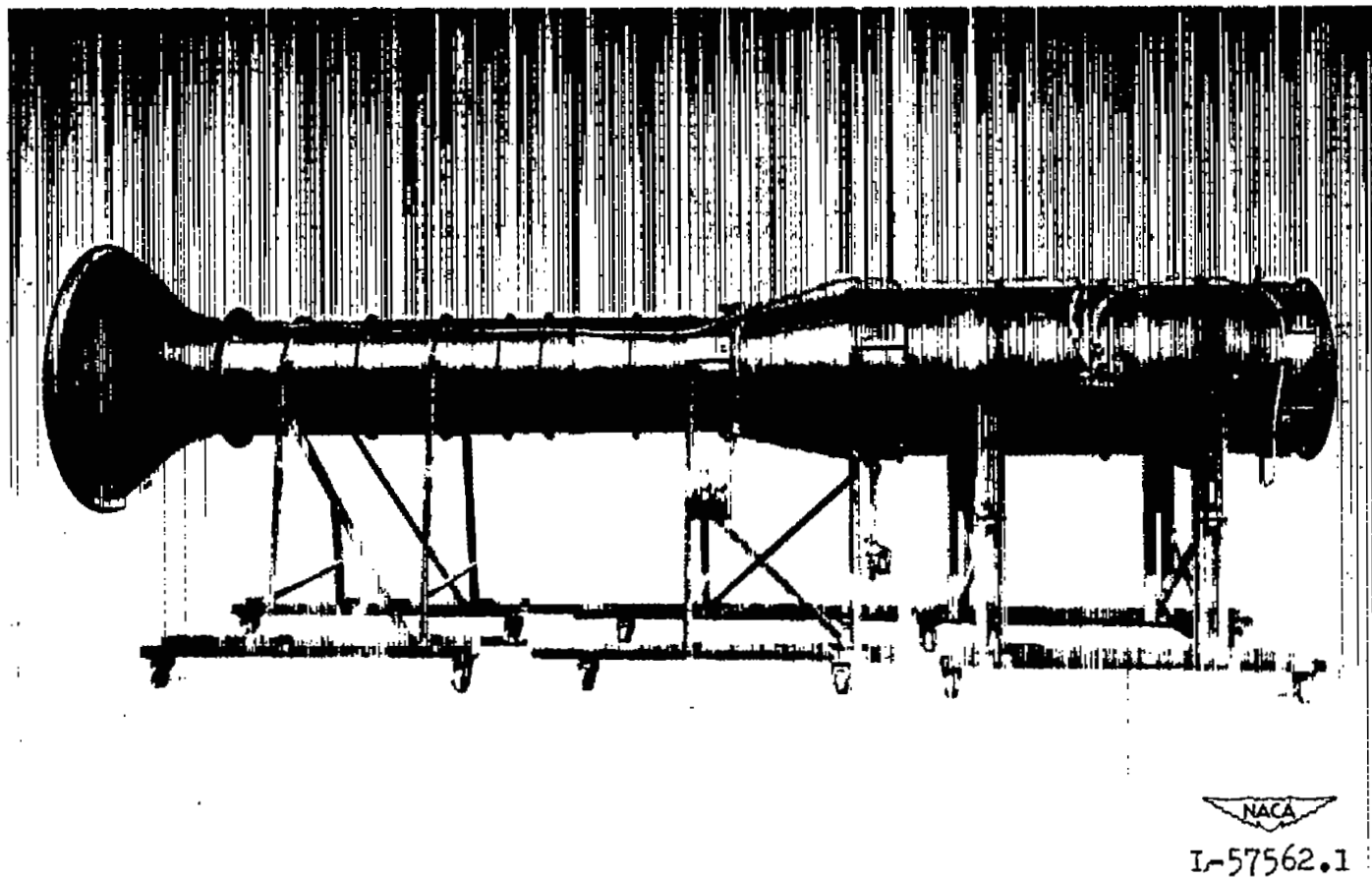


Figure 2.- Arrangement of setup showing inlet pipe and tail pipe.

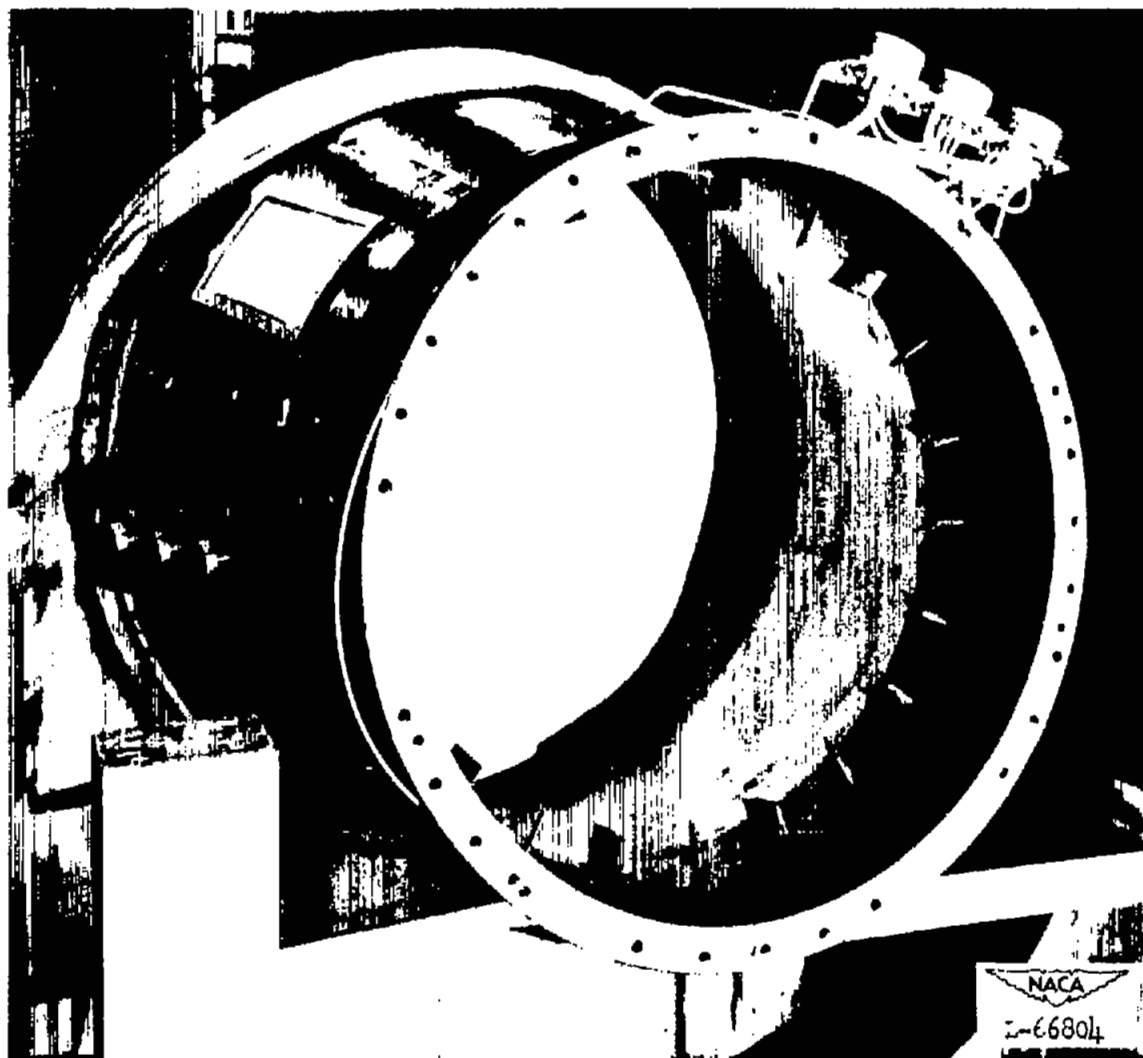
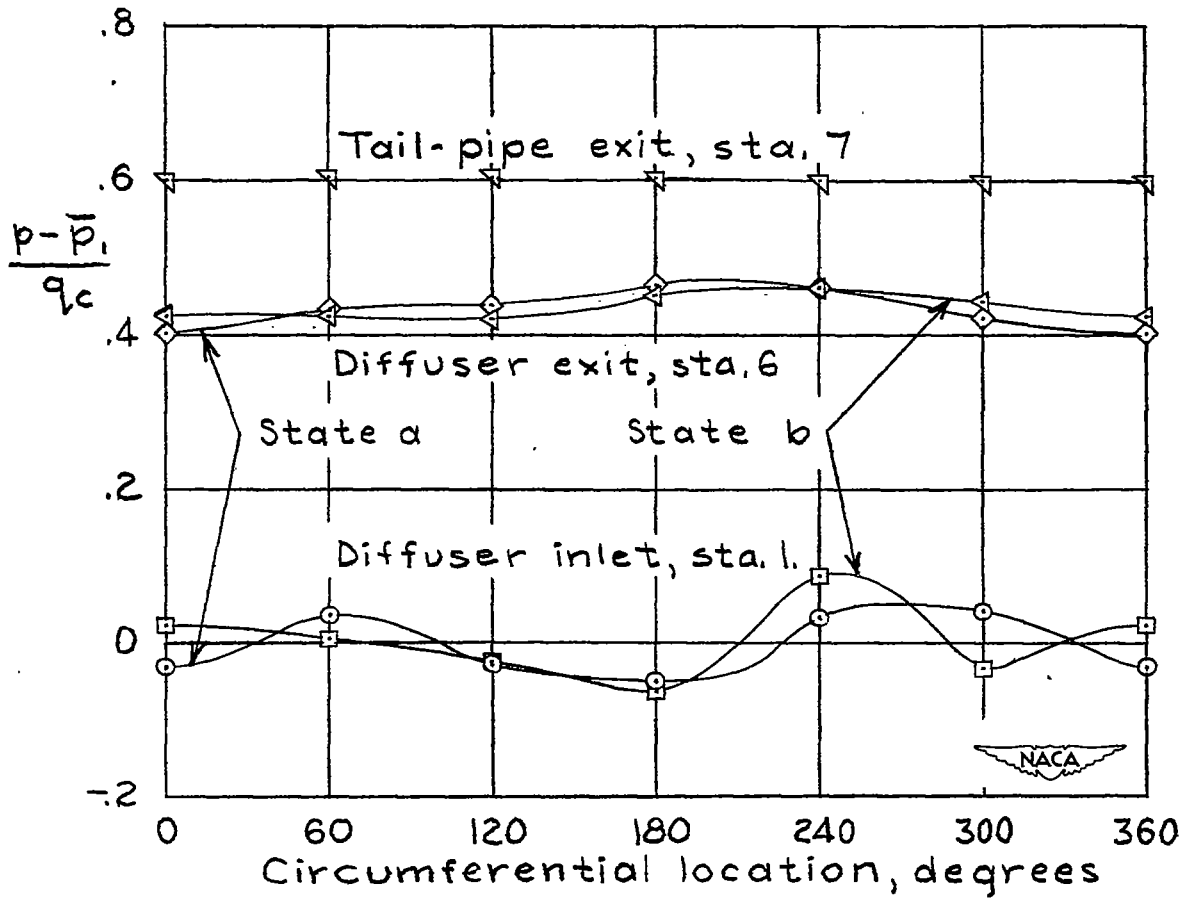
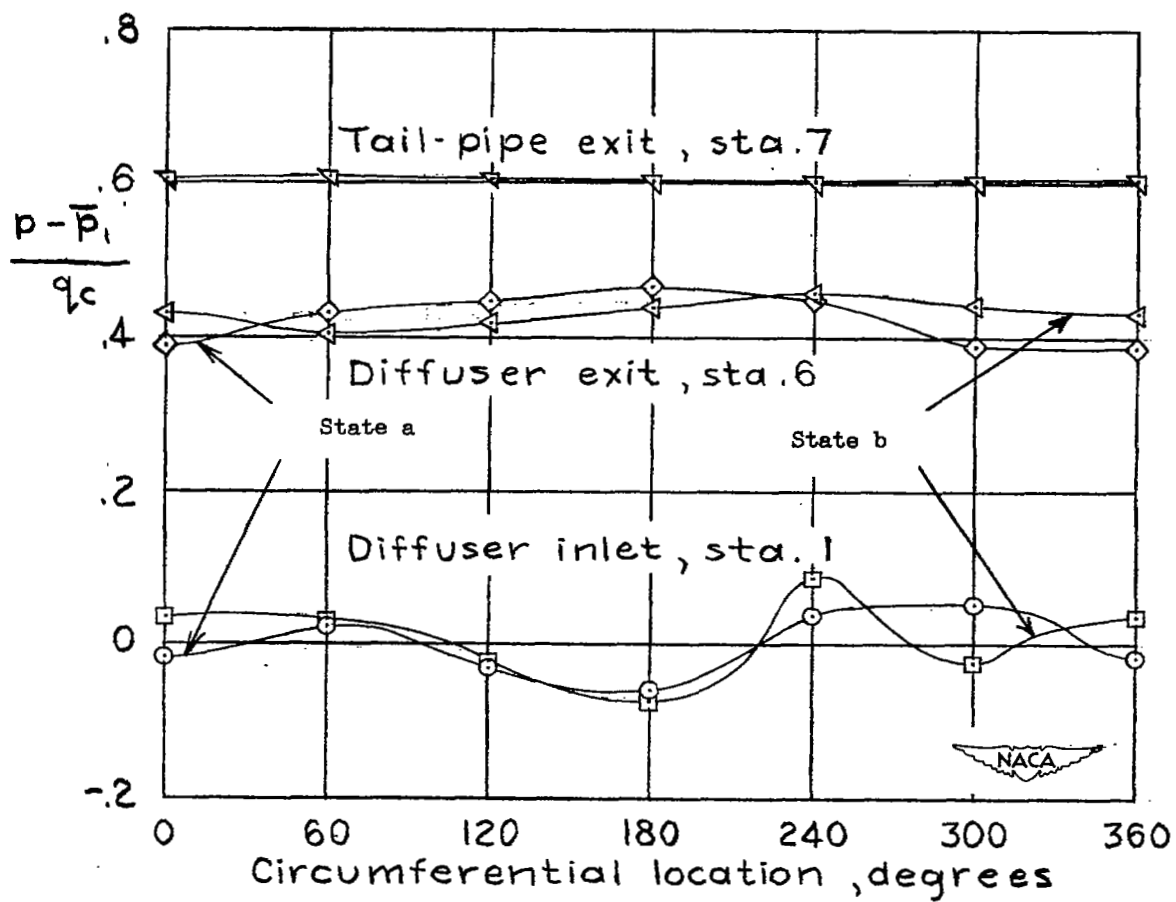


Figure 3.- View from diffuser inlet showing installation of 22 counter-rotating vortex generators at an angle of attack of 15° .



(a) $\frac{p_1}{H_0} = 0.97.$

Figure 4.- Circumferential variation of static pressure. No vortex generators.



(b) $\frac{P_1}{H_0} = 0.83.$

Figure 4.- Concluded.

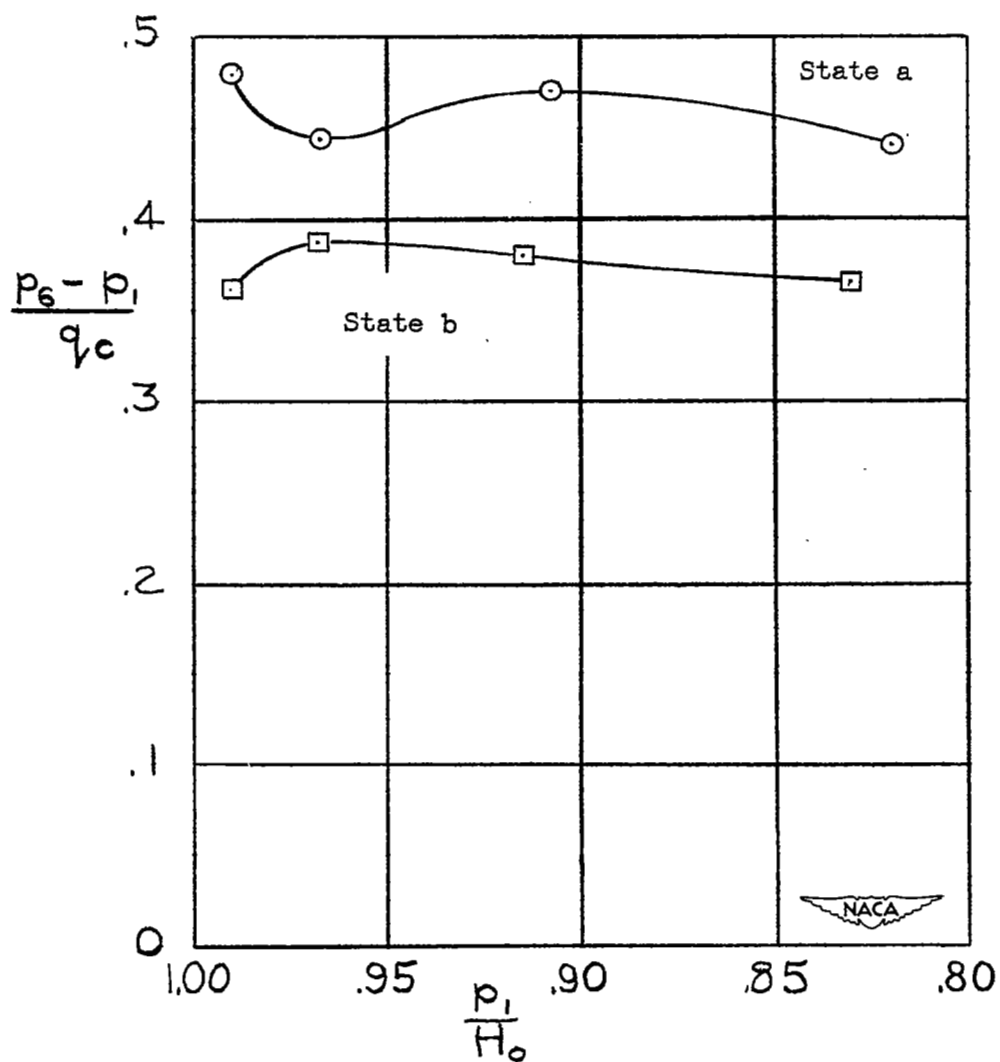


Figure 5.- Apparent two-valued diffuser characteristics from one-tube diffuser data.

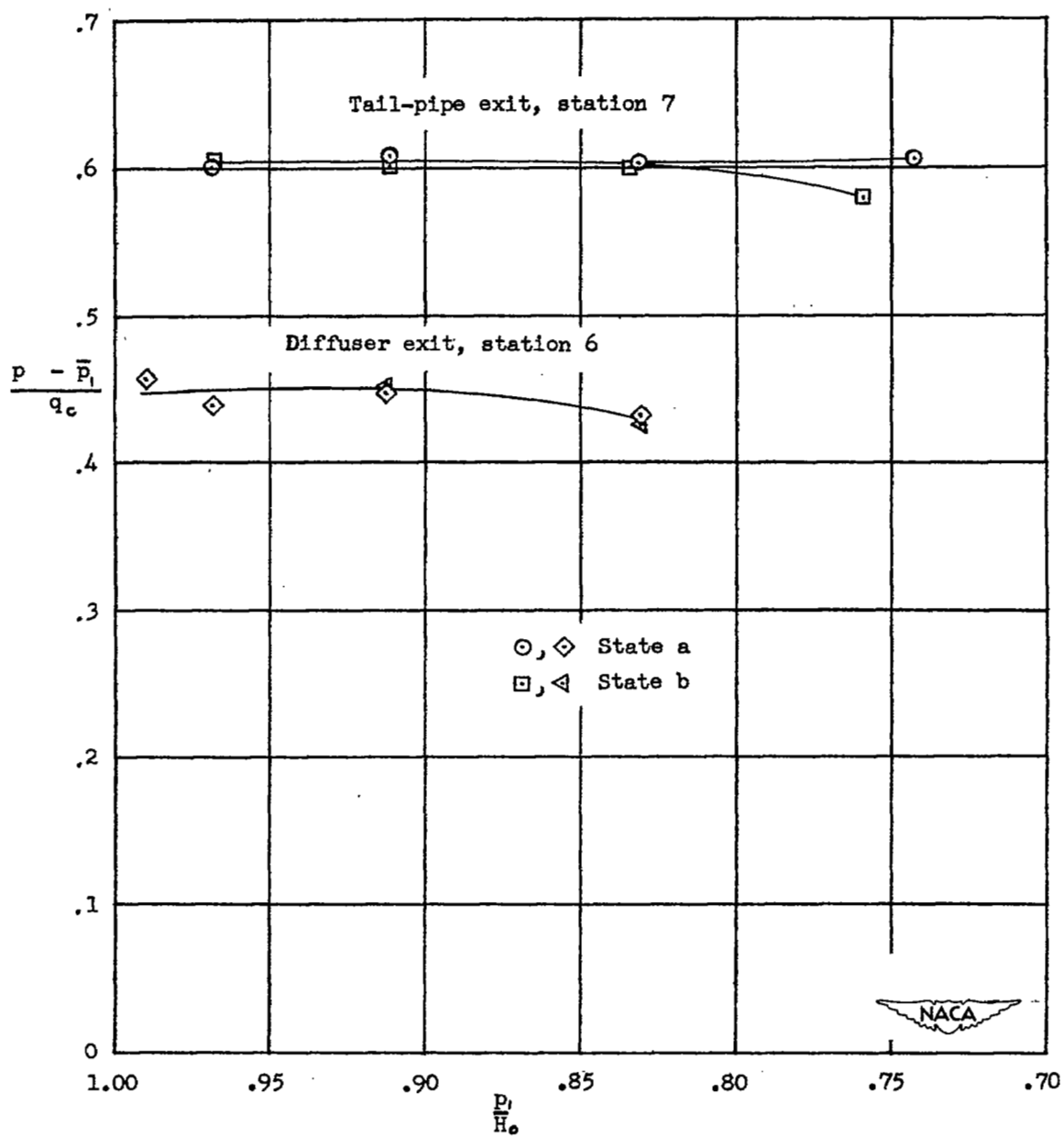


Figure 6.- Static-pressure rise in diffuser and in the diffuser-tailpipe combination. No vortex generators.

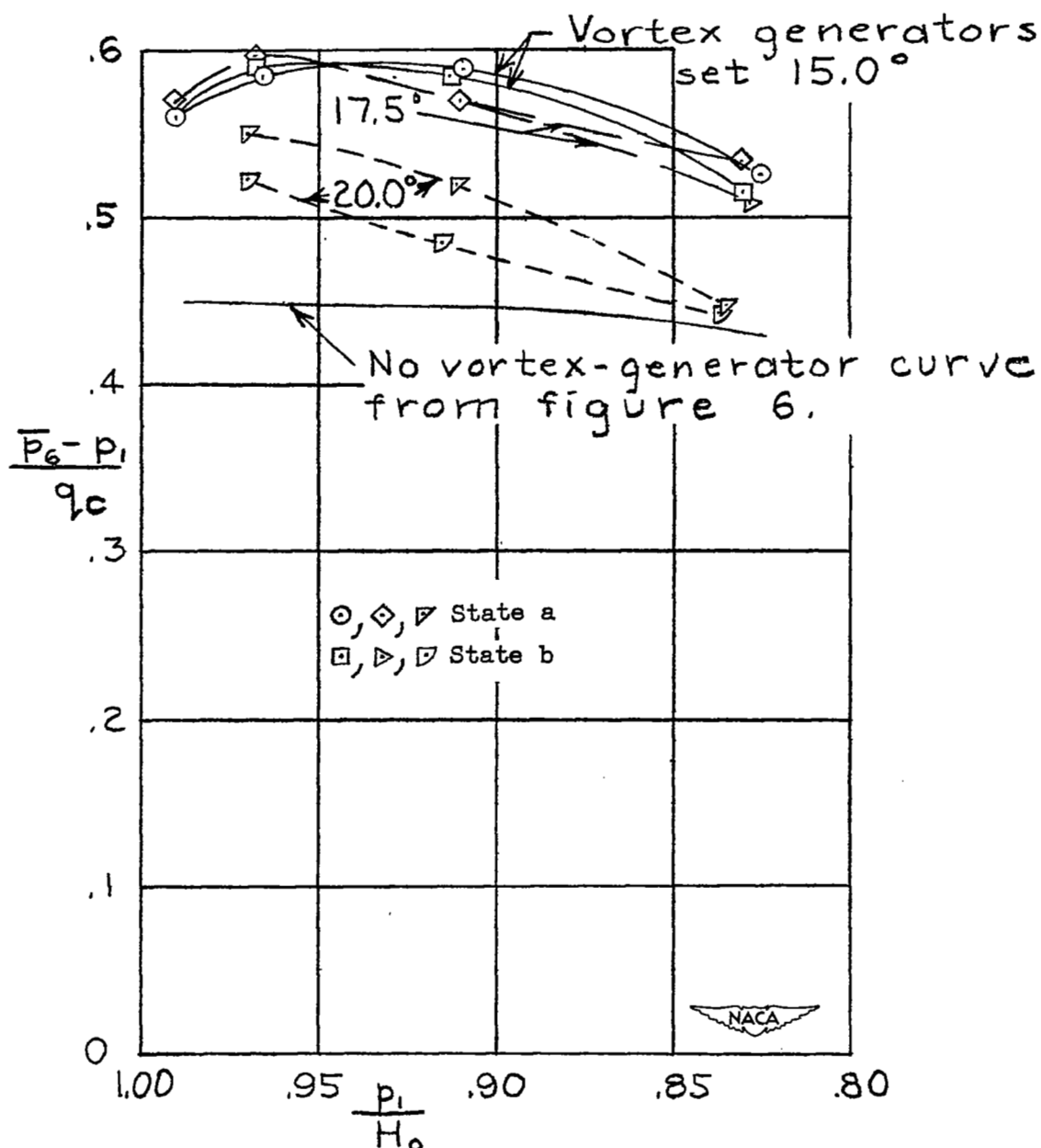
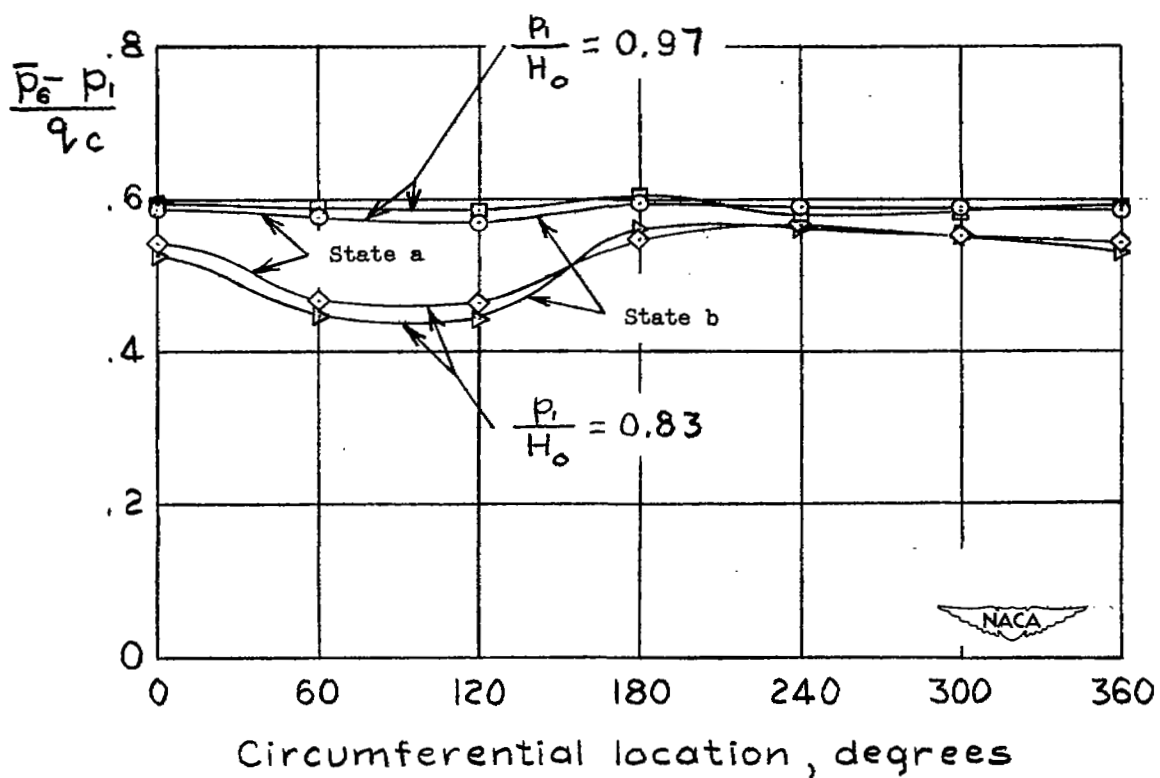
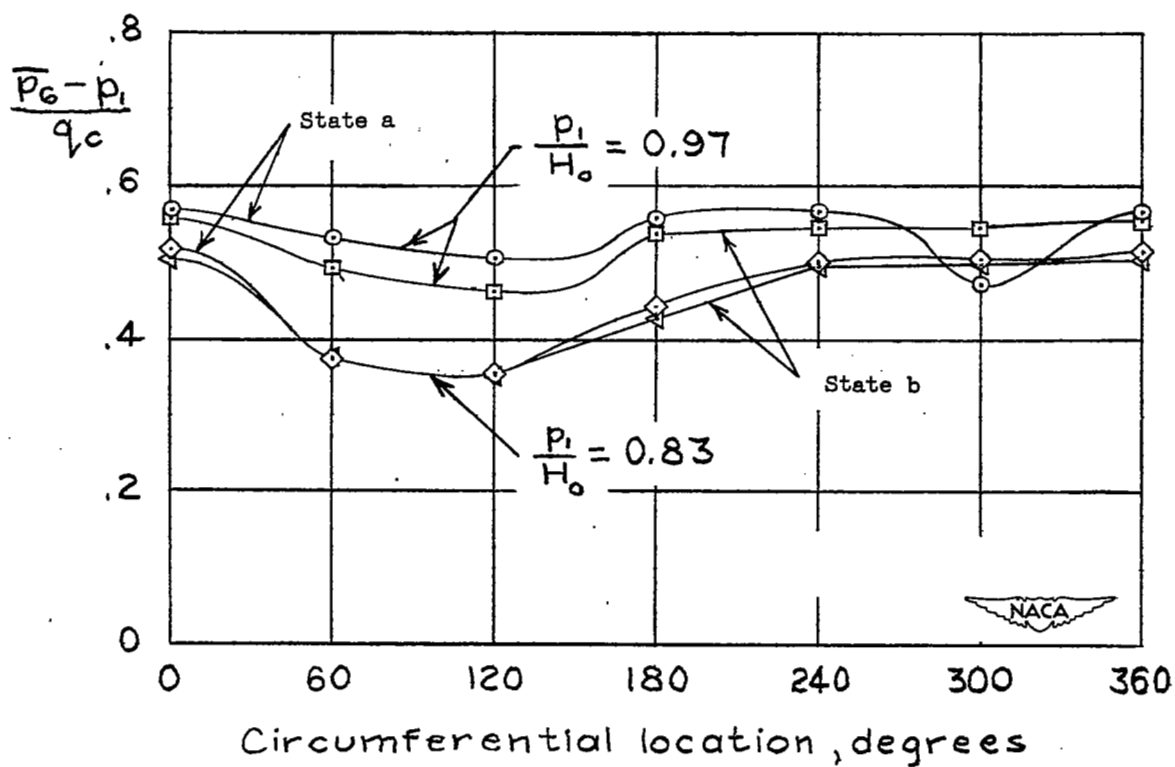


Figure 7.- Static-pressure rise in the diffuser with 22 counterrotating vortex generators at several angles of attack ($\frac{b}{b} = 2.9$).



(a) 15° angle of attack.

Figure 8.- Circumferential variation of static pressure at the end of the diffuser with 22 counterrotating vortex generators ($\frac{s}{b} = 2.9$).



(b) 20° angle of attack.

Figure 8.- Concluded.

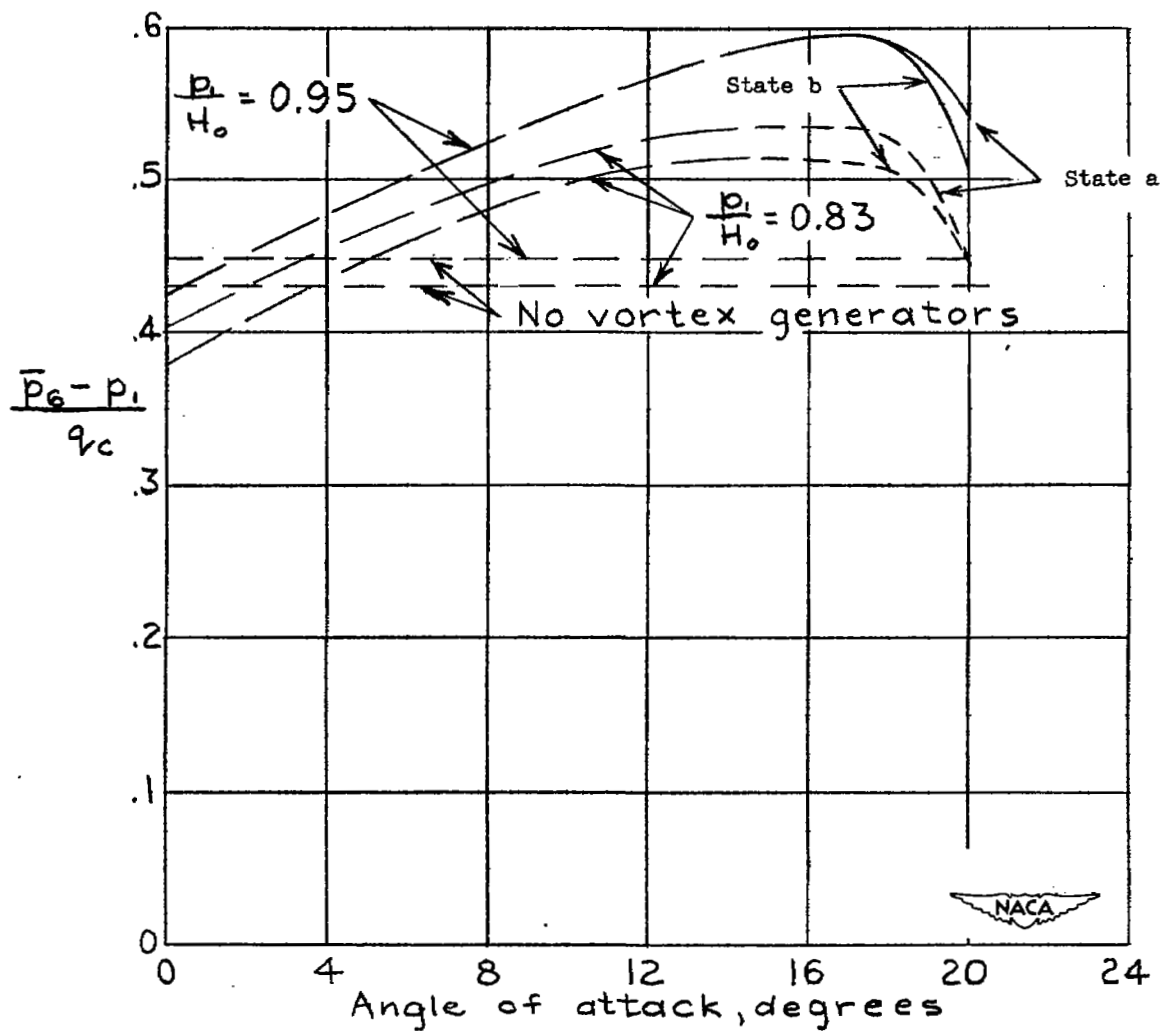


Figure 9.- Effect of vortex-generator angle of attack on the diffuser static-pressure rise for 22 counterrotating vortex generators $\left(\frac{s}{b} = 2.9\right)$.

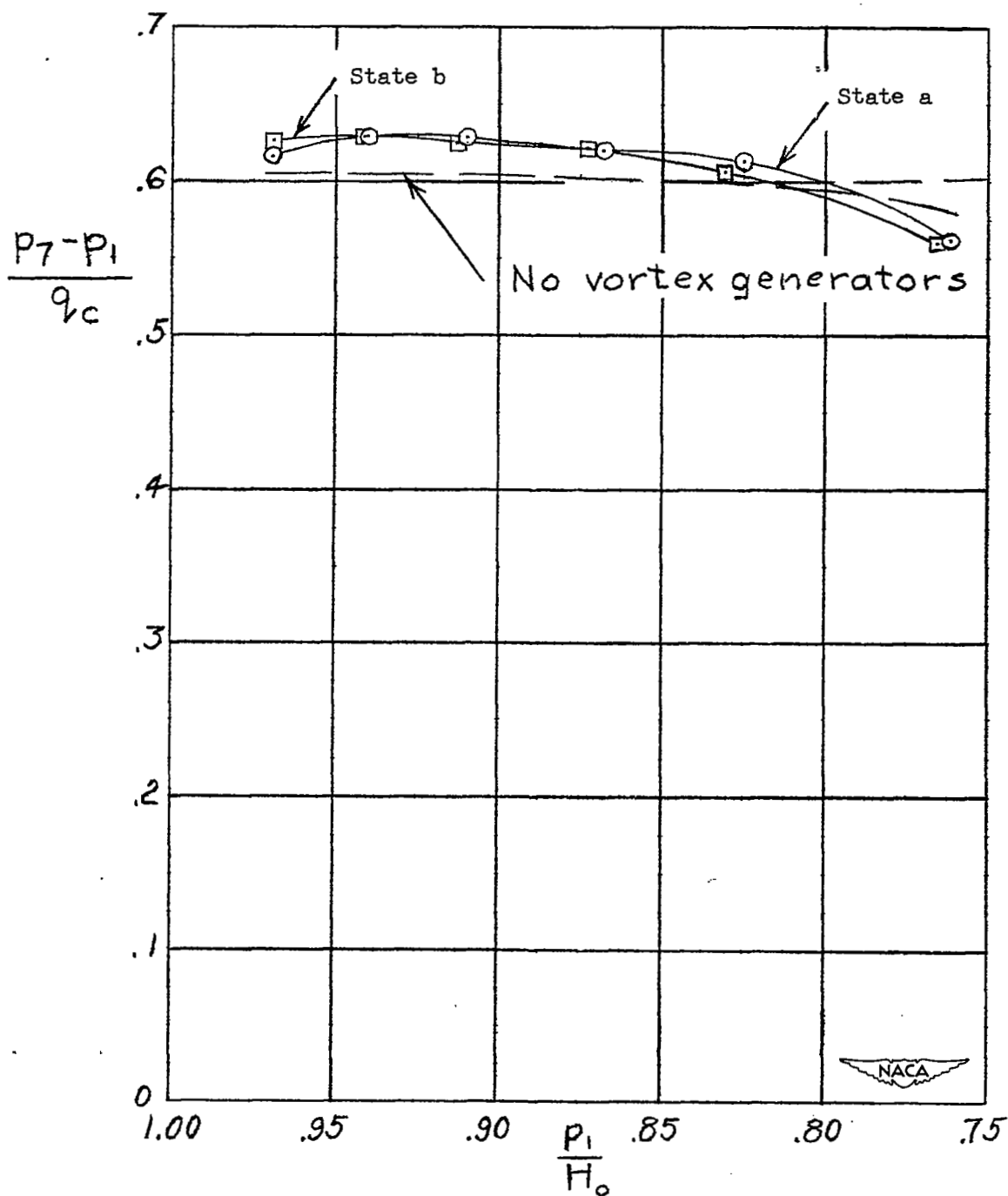
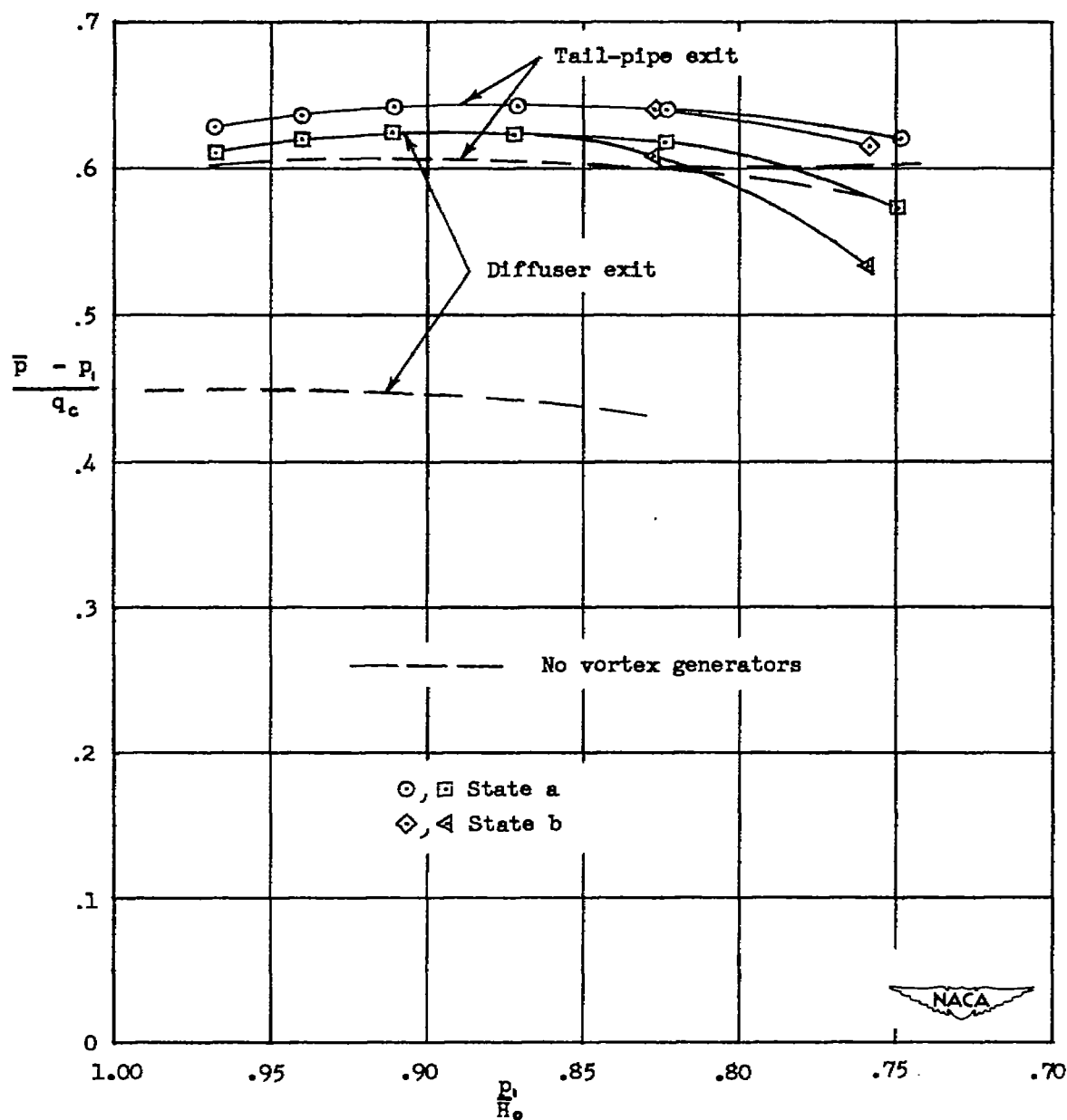
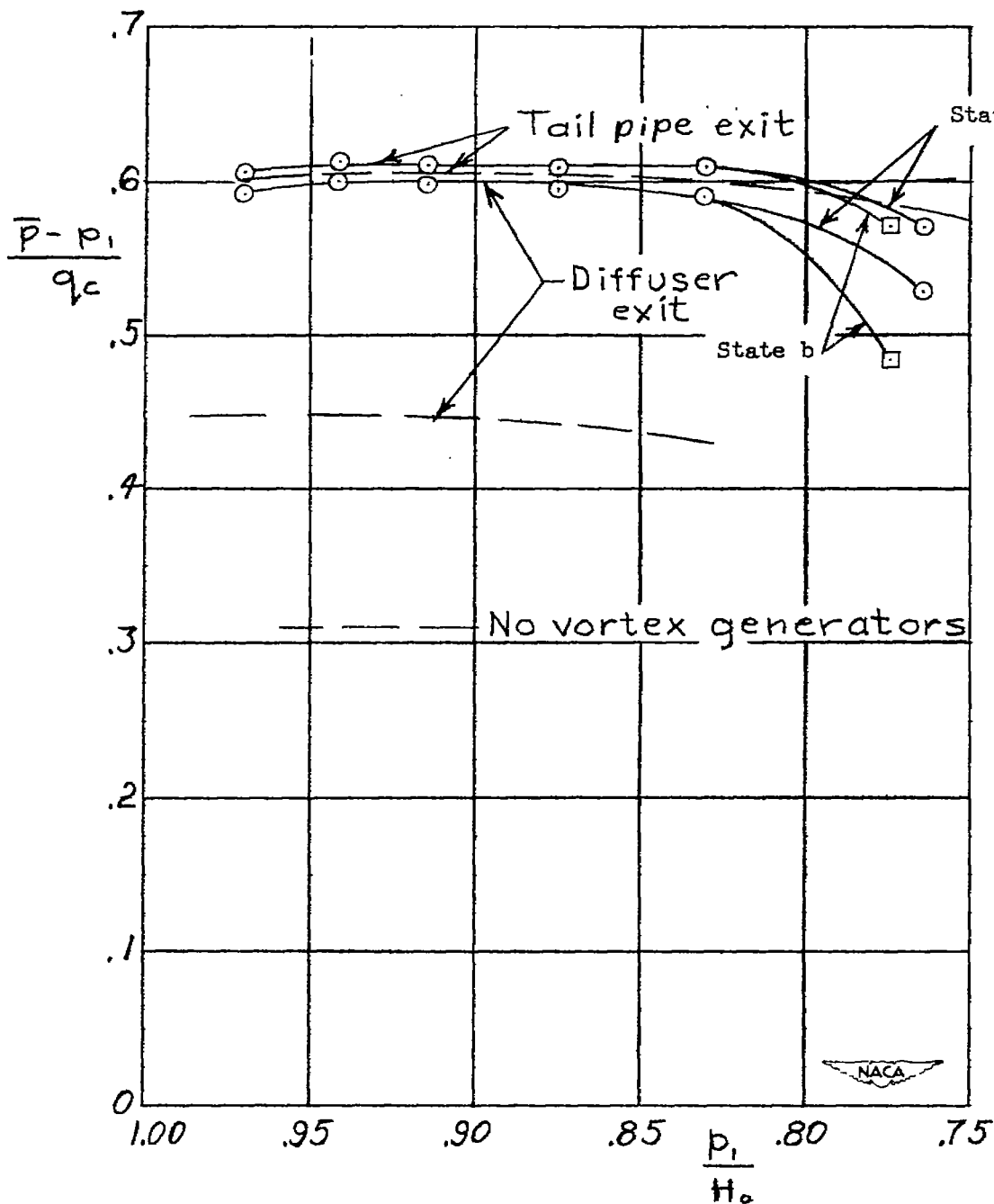


Figure 10.- Static-pressure rise to the end of the tail pipe with 22 counterrotating vortex generators $\left(\frac{B}{b} = 2.9, \alpha = 15^\circ\right)$.



(a) 15° angle of attack.

Figure 11.- Static-pressure rise with 28 vortex generators $\left(\frac{B}{b} = 2.2\right)$.



(b) 20° angle of attack.

Figure 11.- Concluded.

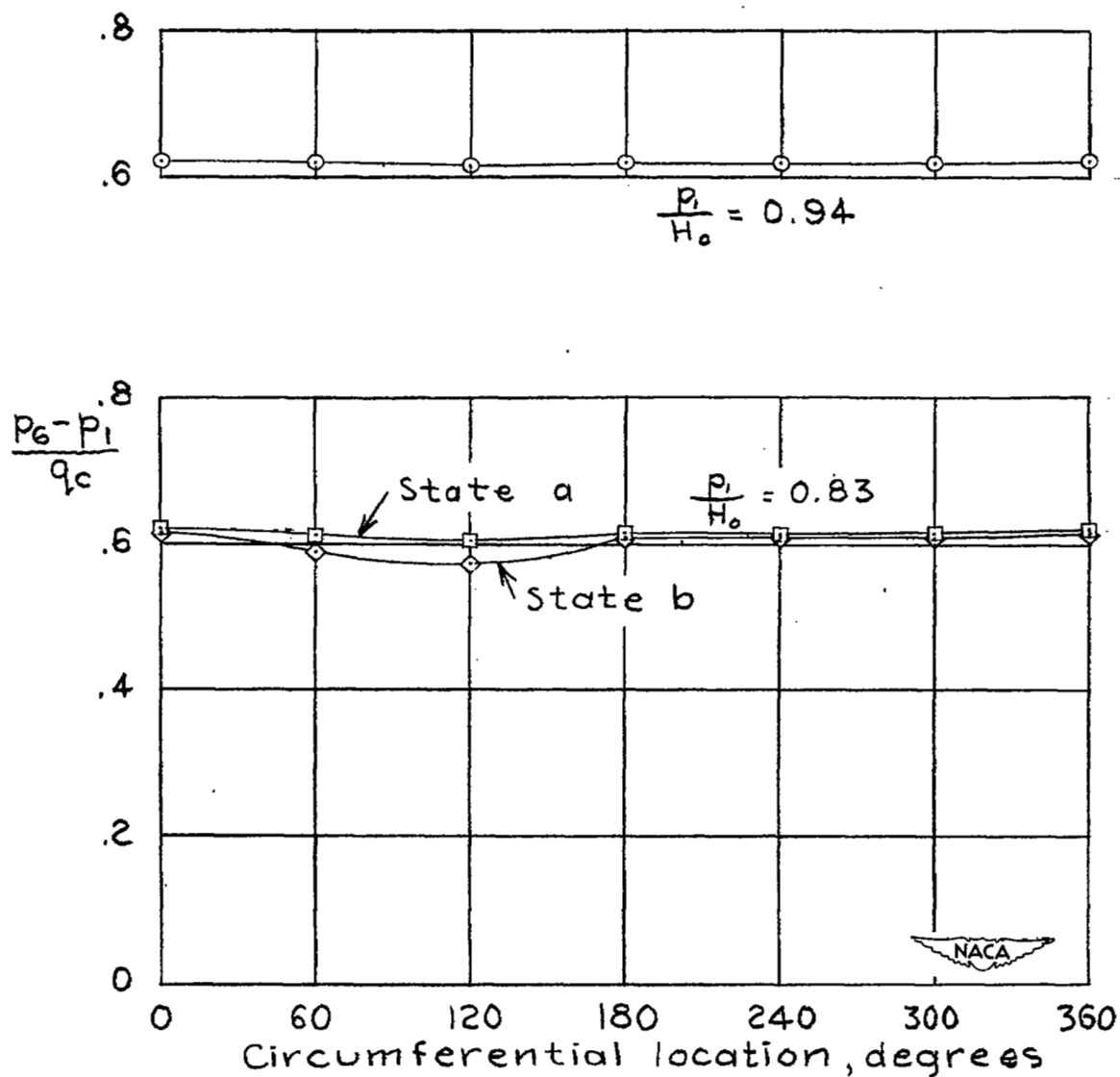
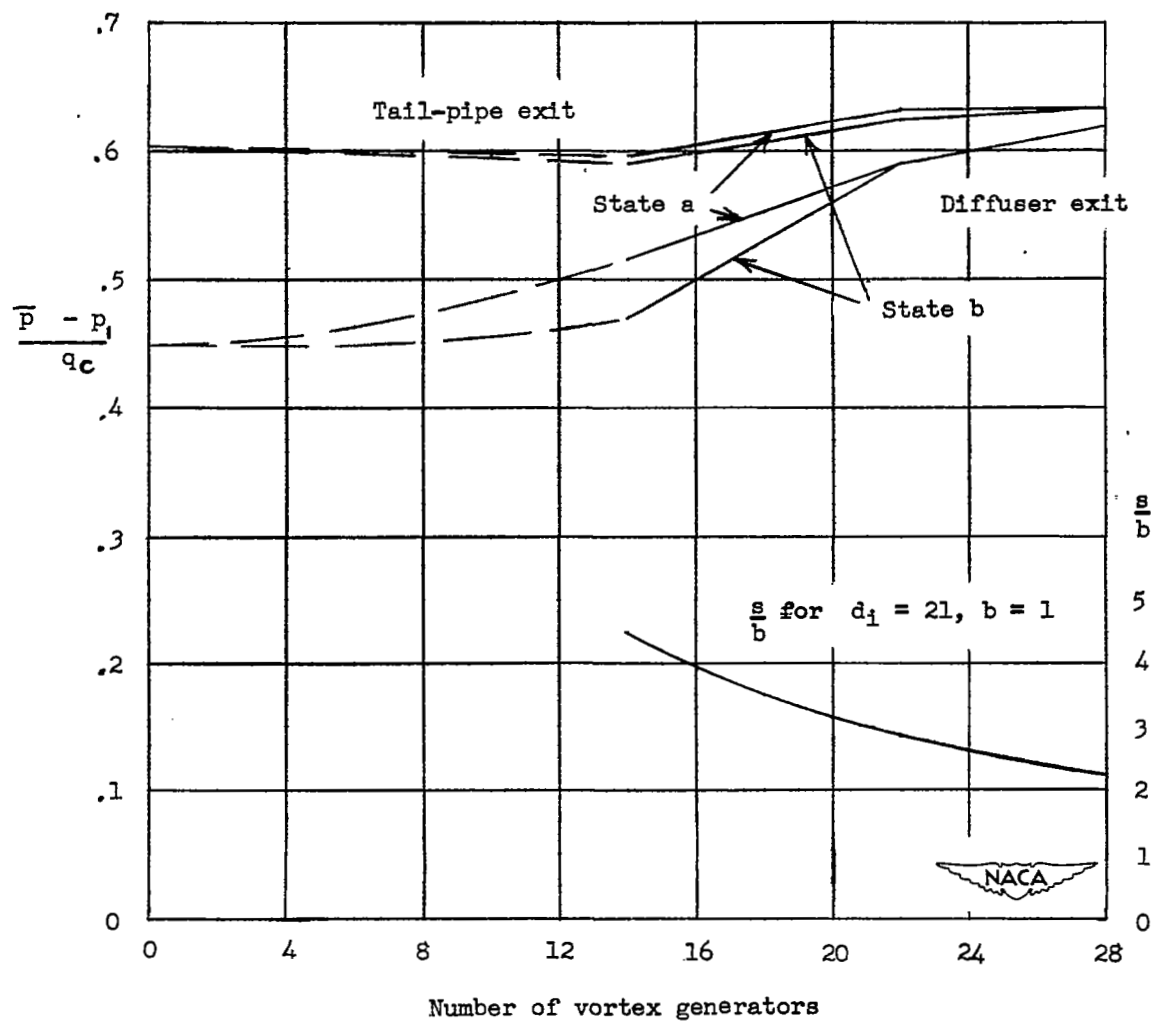


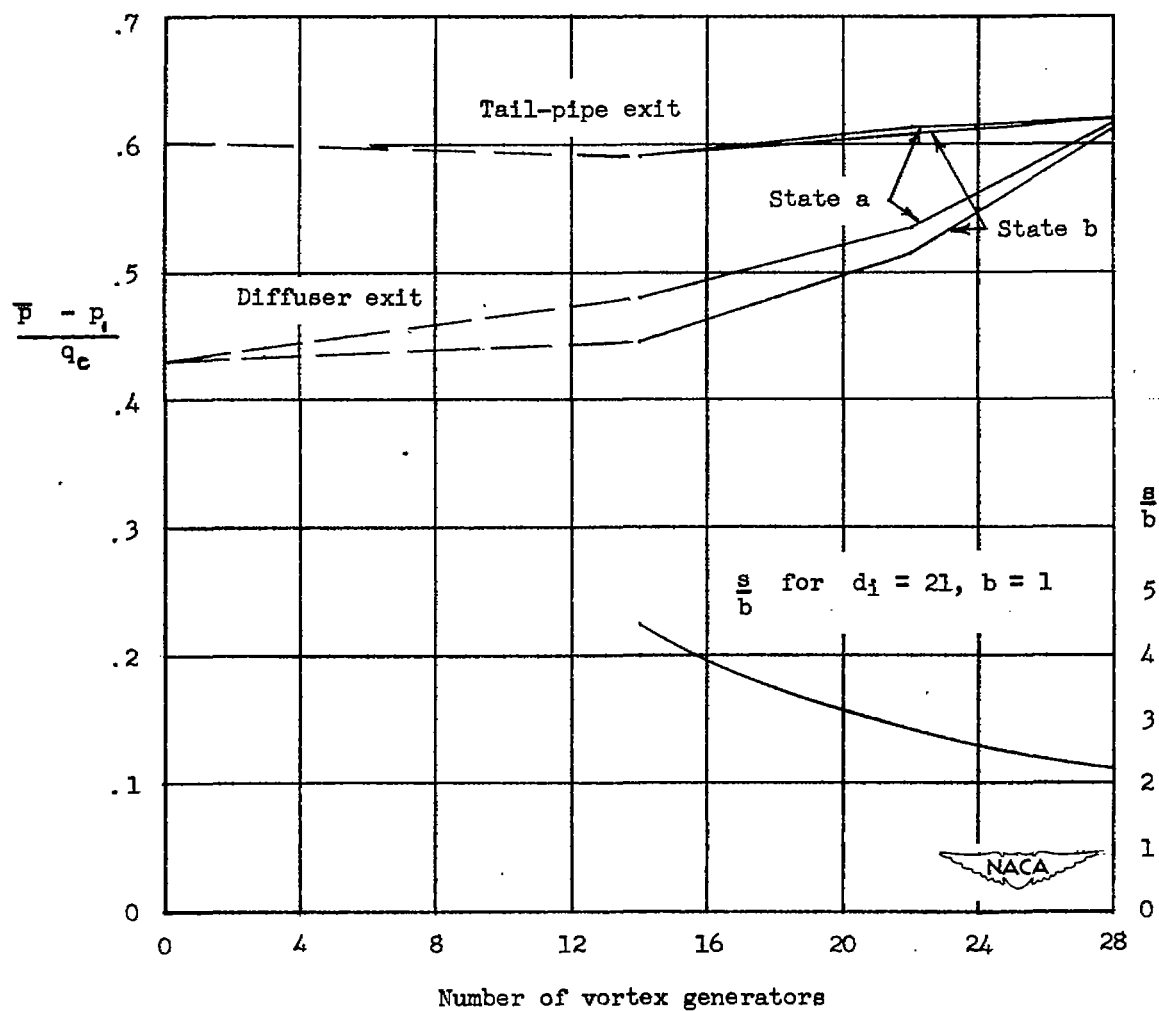
Figure 12.- Circumferential variation of static pressure at the end of the diffuser with 28 counterrotating vortex generators set at 15°

$$\left(\frac{s}{b} = 2.2\right).$$



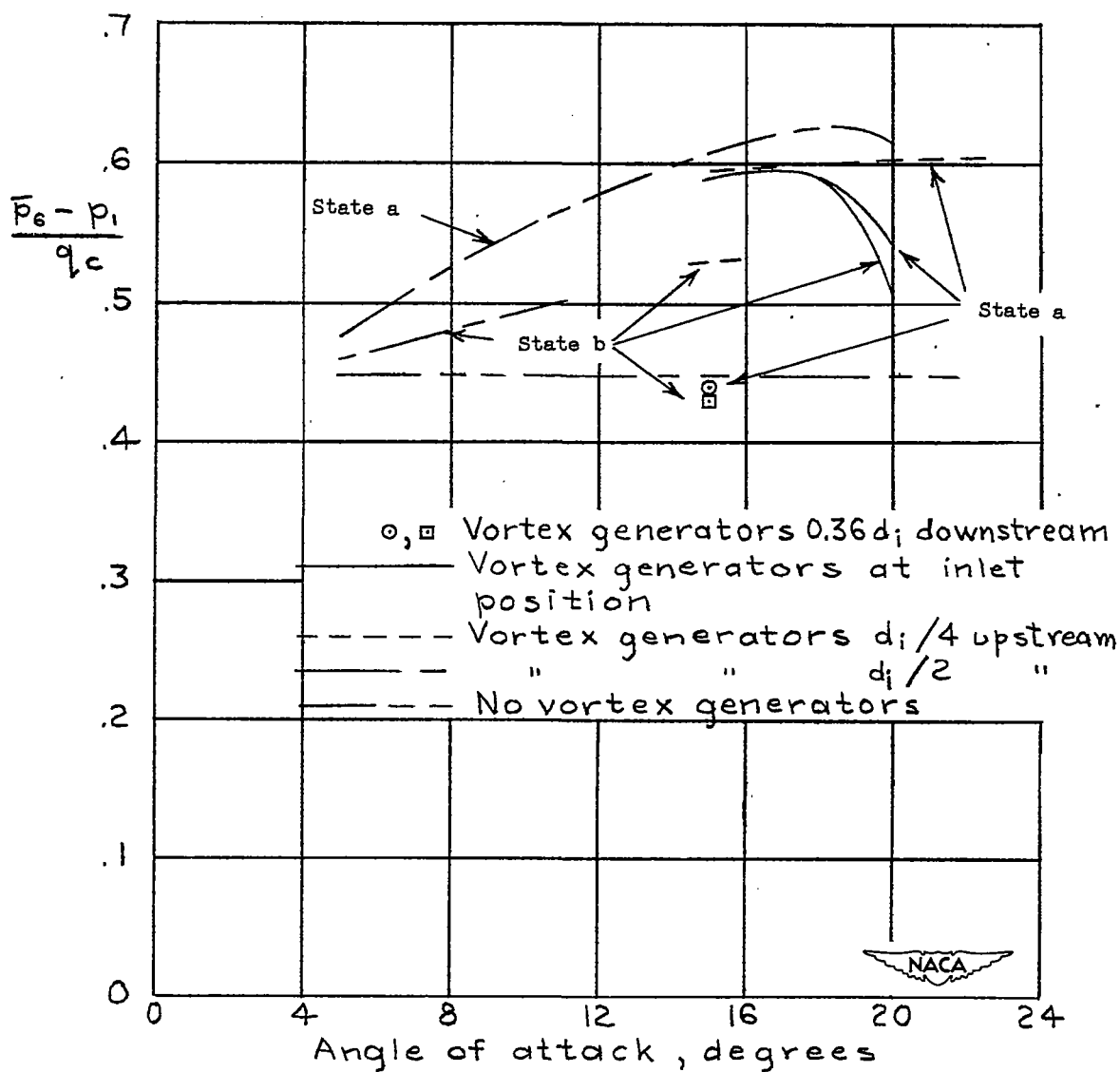
(a) $\frac{p_1}{H_0} = 0.95$.

Figure 13.- Effect of number of counterrotating vortex generators on the static-pressure rise ($\alpha = 15^\circ$).



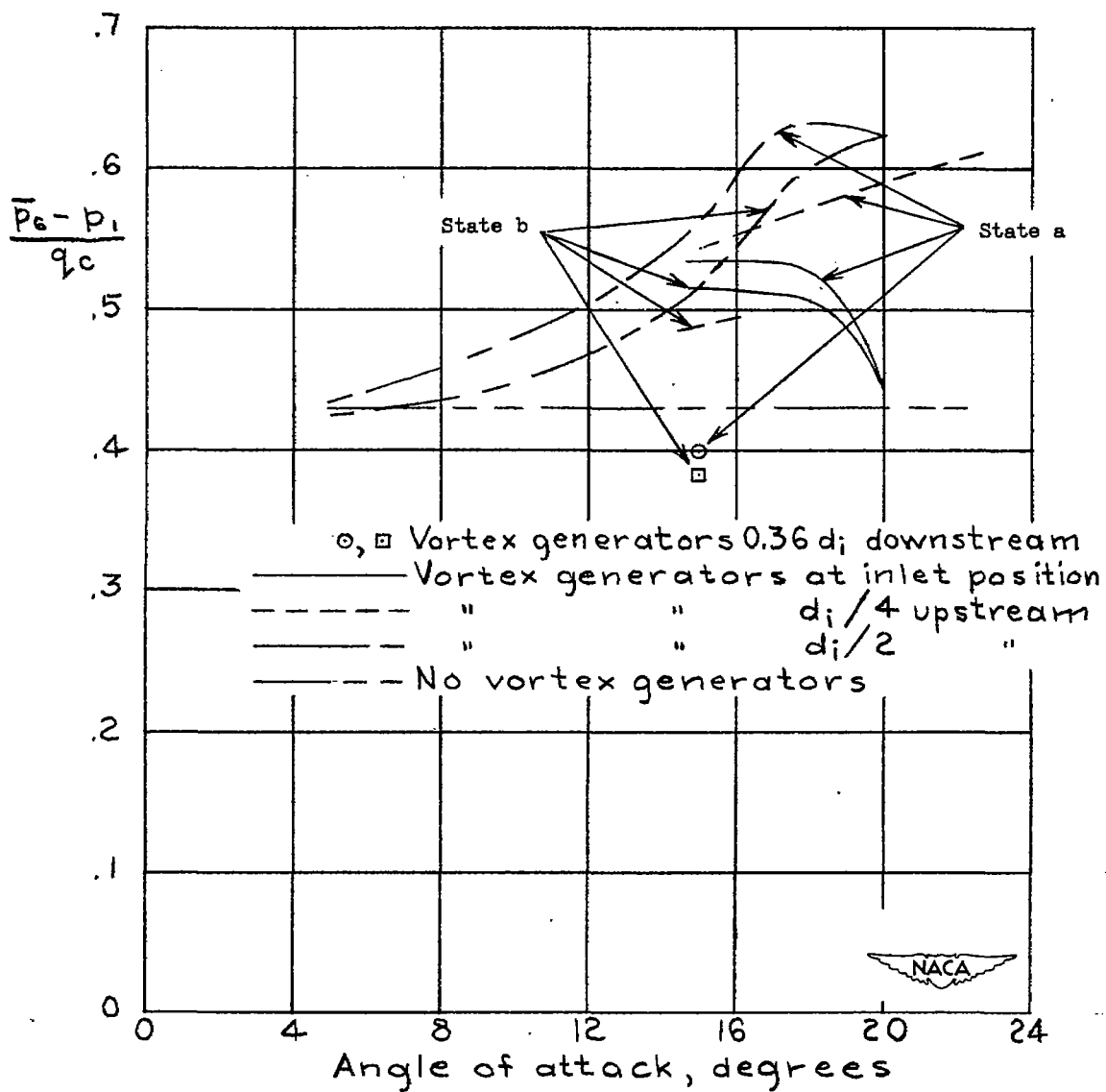
(b) $\frac{P_1}{H_0} = 0.83.$

Figure 13.- Concluded.



(a) $\frac{p_1}{H_0} = 0.95$.

Figure 14.- Effect of vortex-generator angle of attack on the diffuser static-pressure rise for 22 counterrotating vortex generators at different longitudinal locations in the inlet duct $\left(\frac{S}{b} = 2.9\right)$.



(b) $\frac{p_1}{H_0} = 0.83.$

Figure 14.- Concluded.

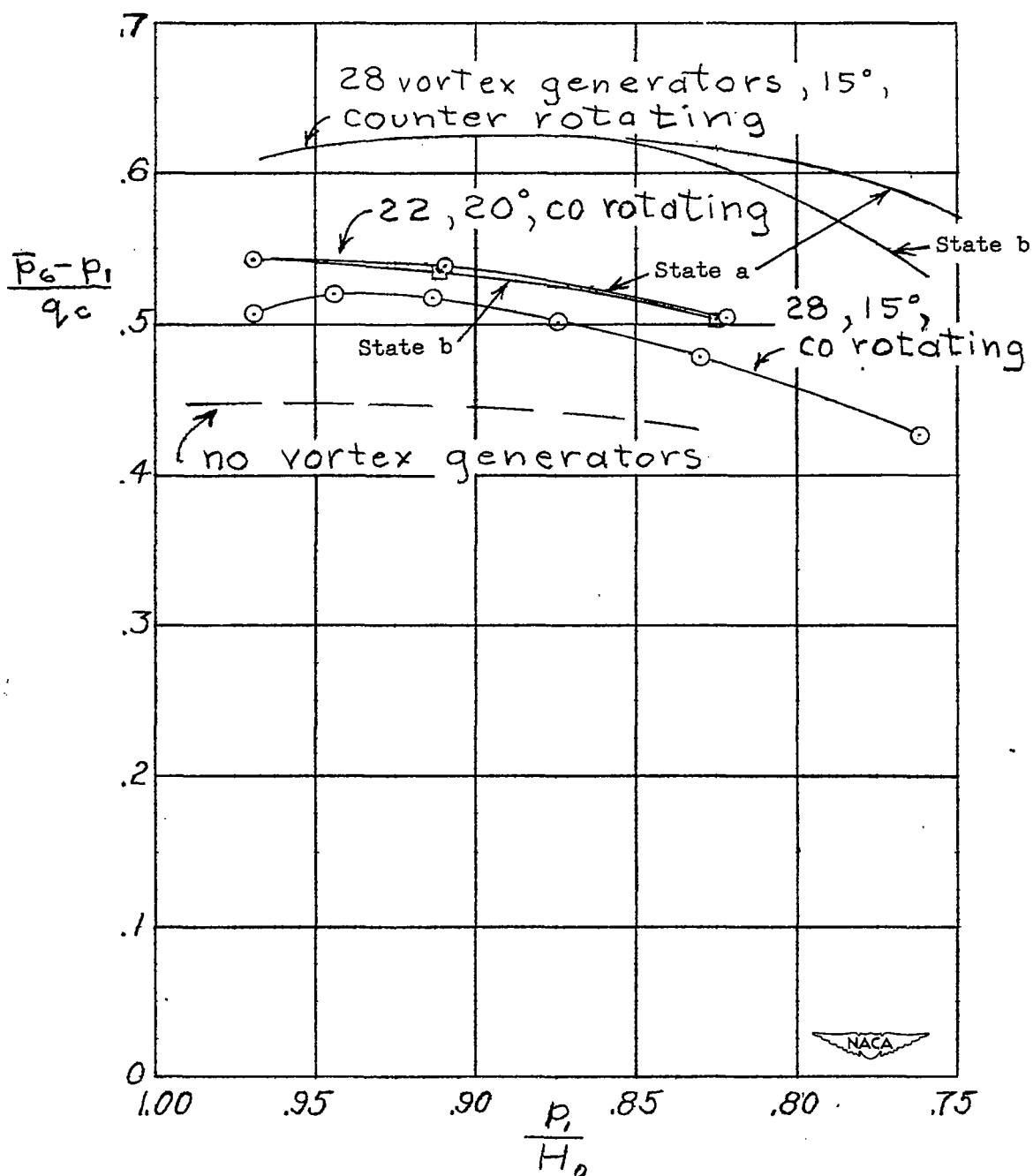


Figure 15.- Comparison of static-pressure rise in the diffuser for counterrotating and corotating vortex generators.

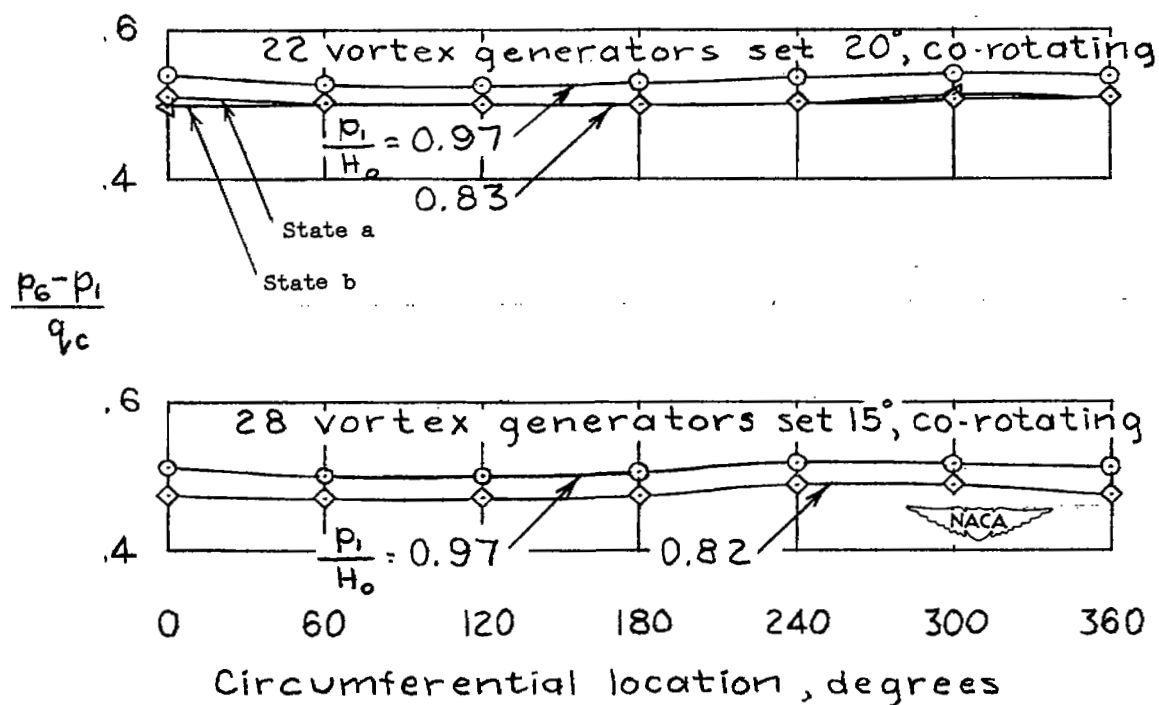


Figure 16.- Circumferential variation of static pressure at the end of the diffuser with corotating vortex generators.

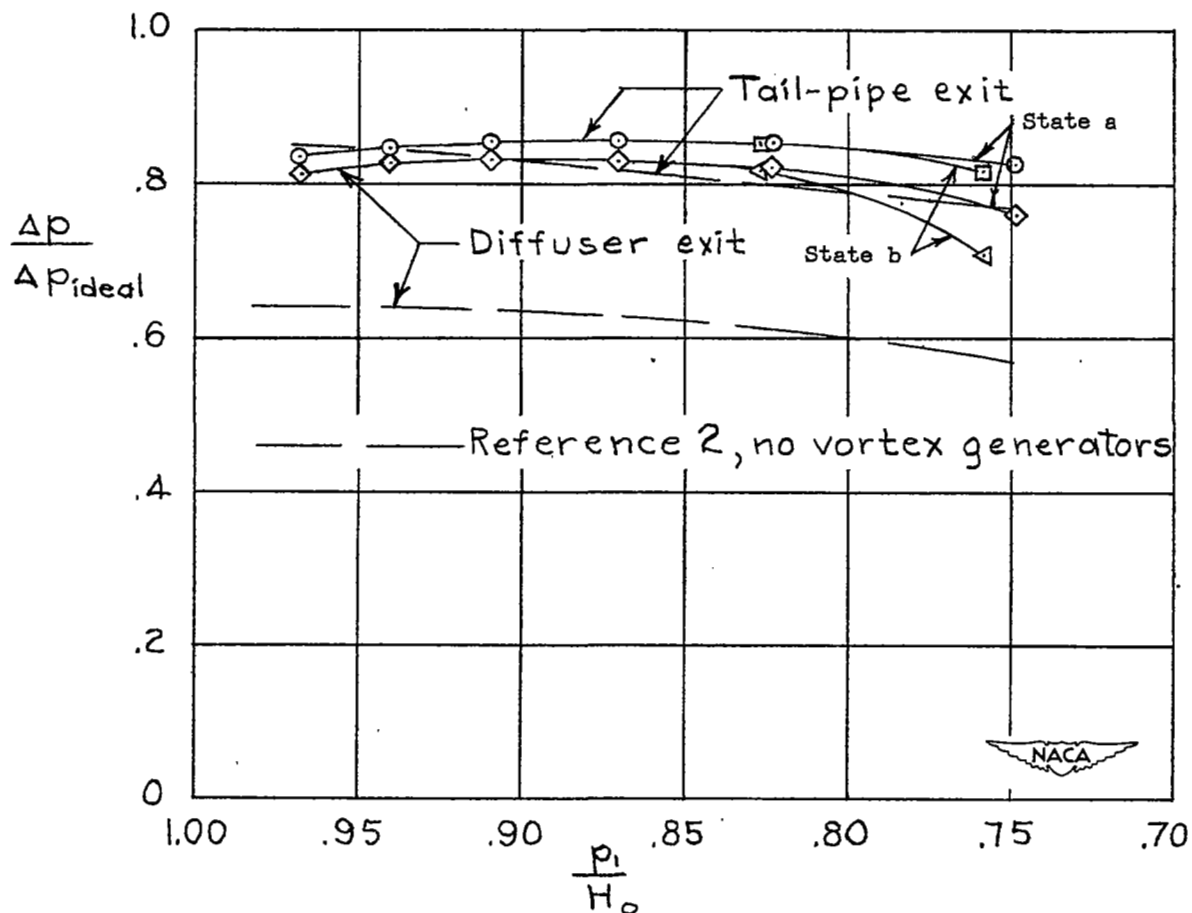


Figure 17.- Comparison of pressure rise with and without vortex generators on basis of diffuser effectiveness.